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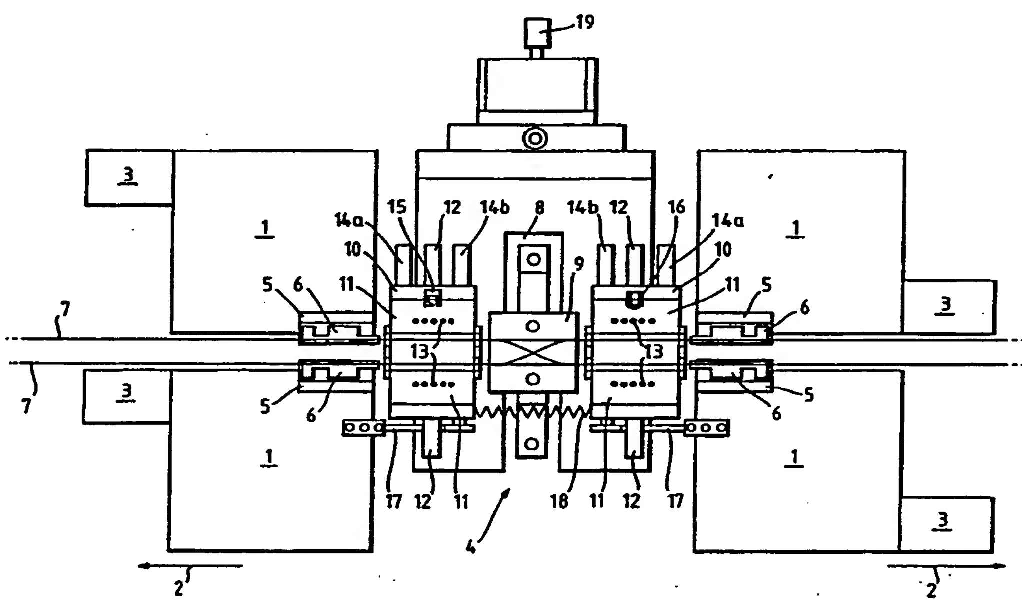

(57) Abstract

A 4x4 fibre coupler is made by forming a matrix of four 2x2 fibre couplers (C1 to C4). The apparatus comprises a respective assembly for forming each of the 2x2 fibre couplers (C1 to C4), and link means (9) for linking the 2x2 fibre couplers in a predetermined way. Each assembly comprises a holder (5, 6) for holding a twisted pair of optical fibres (f1 to f4), heating means (11) for raising the temperature of the optical fibres to their fusion temperature, and tensioning means (13) for stretching the optical fibres. The assemblies are such that each heating means heats the associated optical fibres (f1 to f4) over a constant zone thereof during the stretching process.

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APPARATUS FOR MANUFACTURING FIBRE COUPLER ARRAYS

This invention relates to apparatus for, and a method of, manufacturing fibre coupler arrays, in particular broadband 4 x 4 fibre coupler arrays and hybrid concatenated fused taper devices.

There is an increasing interest in the utilisation of passive optical networks in telecommunication local loops. Most of these systems rely on the splicing together of large numbers of individual (2 x 2 and 2 x 1) couplers to achieve the multiple splits required. Such coupler arrays are bulky, have a poor performance, are time-consuming to manufacture, and have high excess losses.

The aim of the invention is to provide apparatus for, and a method of, manufacturing fibre coupler arrays which do not suffer from the disadvantages of known techniques.

The present invention provides apparatus for manufacturing an n x n fibre coupler by forming a matrix of m 2 x 2 fibre couplers, the apparatus comprising a respective assembly for forming each of the 2 x 2 fibre couplers, and link means for linking the 2 x 2 fibre couplers in a pre-determined way, each assembly comprising a holder for holding a twisted pair of optical fibres, heating means for raising the temperature of the optical fibres to their fusion temperature, and tensioning means for stretching the optical fibres, wherein the assemblies are such that each heating means heats the associated optical fibres over a constant zone thereof during the stretching process.

The advantages of manufacturing a coupler using matrices in a single compact device, as opposed to concatenating individual couplers, are numerous. Thus, an all round improvement in performance results, fibre

clutter is minimised, and the size of installed coupler devices is reduced. The cost and time of manufacture is also substantially reduced.

In a preferred embodiment, n = 4 and m = 4. In this case, the apparatus can be used to make a 4 x 4 broadband coupler device. Although the apparatus could be used to manufacture couplers having larger arrays (e.g. 4 x 8, 16 x 16 and 32 x 32), the probability of achieving successful production declines as the array increases. The 4 x 4 device offers the optimum balance between performance, complexity, size and production yield, though 2 x 4 devices are also useful. Both the 2 x 4 and 4 x 4 devices offer a very practical building block for larger splitter matrices. There is an additional advantage in that 80% of those devices failing as 4 x 4s will yield satisfactory 2 x 4 devices.

Advantageously, each holder is mounted on a respective table, the tables being supported for reciprocal rectalinear movement on a common base, and each table is provided with a stepper motor for reciprocation of that table with respect to the base. Preferably, for a 4 x 4 device, the tables are mounted in pairs on opposite sides of the heating means.

Preferably, the heating means is constituted by a pair of heating assemblies, the heating assemblies being positioned on opposite sides of the link means and adjacent to a respective pair of tables. Conveniently, each heating assembly is constituted by a pair of gas burners, each of which is aligned with a respective twisted pair of optical fibres. A respective ceramic crucible may be associated with each of the gas burners, the ceramic crucibles being sized and shaped to surround the twisted pairs of optical fibres.

Advantageously, the heating assemblies are supported on the base for reciprocal rectalinear movement in the same direction as the tables, and each heating assembly is driven by the stepper motor of one of the adjacent tables via gearing which reduces the speed of movement of that heating assembly to half the speed of movement of the associated pair of tables.

Preferably, the link means comprises an insert formed with channels for directing the optical fibres in pre-determined paths between the 2 x 2 fibre couplers. Conveniently, the channels are such that none of the optical fibres positioned therein are bent at a greater radius than the minimum bend radius.

The invention also provides a method of manufacturing an n x n fibre coupler, the method comprising the steps of forming a matrix of m 2 x 2 fibre couplers, and linking the 2 x 2 fibre couplers in a pre-determined way.

Apparatus for manufacturing broadband 4 x 4 fibre coupler arrays and constructed in accordance with the invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a schematic plan view of the apparatus;

Fig. 2 is a flow chart of the manufacturing process; and

Fig. 3 is a diagrammatic representation of the processing control and monitoring arrangements of the apparatus.

Referring to the drawings, Fig. 1 shows fibre coupler manufacturing apparatus having four tables 1 mounted on a base (not shown). As shown in Fig. 3, the apparatus is intended to form a 4 x 4 coupler array by coupling each one of four fibres f1 to f4 to each of the other fibres by

four 2 x 2 fibre couplers C1 to C4. Thus, the coupler C1 couples the fibres f1 and f2, the coupler C2 couples the fibres f3 and f4, the coupler C3 couples the fibres f1 and f3 and the coupler C4 couples the fibres f2 and f4. The tables 1 are movable, in the directions indicated by the arrows 2, by respective stepper motors 3. The tables 1 are mounted in pairs on opposite sides of a fibre coupler manufacturing region indicated generally by the reference numeral 4. Each table 1 has fixed thereto a carriage 5 in which a respective cartridge 6 is rotatably mounted. Each cartridge 6 is formed with a pair of parallel channels (not shown) for receiving a respective optical fibre f1 to f4 of a respective two-core fibre optic cable 7. In use, the optical fibres f1 to f4 are clamped in pairs within cartridges 6, the cartridges being rotatable relative to their carriages 5 to twist the fibres.

A cross-over bracket 8 is positioned centrally within the region 4, the bracket 8 supporting an insert 9 and being fixed to the base. The insert 9 is formed with channels (not shown) which house and restrain the fibres f1 to f4 in this region 4. The channels in the insert 9 are such that none of the fibres f1 to f4 is bent at a greater radius than the minimum bend radius. The fibres f1 to f4 are fixed within the channels in the insert 9, for example by gluing.

A respective heating assembly 10 is positioned between the cross-over bracket 8 and each of the pairs of tables 1. Each heating assembly 10 has a pair of gas burners 11, each of which is aligned with a corresponding pair of fibres f1 and f2, f3 and f4, f1 and f3, and f2 and f4. Each burner 11 is provided with a gas inlet pipe 12, and a row of outlet apertures 13. The gas used is a mixture of oxygen, nitrogen and hydrogen. Each heating assembly 10 is provided with water inlet and outlet pipes 14a, 14b

respectively, by means of which the assemblies can be cooled by the passage of water. One of the heating assemblies 10 is provided with a spark ignitor 15 for igniting the gas at the outlet apertures 13, the other heating assembly being provided with a thermocoupler 16 for measuring the temperature. The output of the thermocoupler is passed to a software-controlled control station (not shown). A respective U-shaped ceramic crucible (not shown) is provided on each gas burner 11, the crucibles each being arranged to surround a respective fibre pair f1 and f2, f3 and f4, f1 and f3, and f2 and f4. The crucibles help to ensure that each fibre pair is heated uniformly, thereby improving the quality of the couplers C1 to C4.

The heating assemblies 10 are slidably mounted on the base for movement in the direction indicated by the arrows 2. Moreover, each assembly 10 is movable by a respective stepper motor 3 together with the adjacent table 1. In order to ensure that each of the burners 11 heats a constant length of the associated pair of fibres f1 and f2, f3 and f4, f1 and f3, and f2 and f4, the heating assemblies 10 are arranged to travel at half the rate of the associated tables 1. This is accomplished by lead screws 17 and appropriate gearing (not shown). A spring 18 is provided for returning the heating assemblies 10 to their original positions after the couplers C1 to C4 have been formed. The height of the heating assemblies 10 can be adjusted by a micrometer 19.

Each of the couplers C1 to C4 is a standard tapered fused coupler, that is to say it is formed by heating and stretching a pair of twisted optical fibres. As with all couplers of this type, it is essential to have careful fibre tension control. The apparatus described above achieves this control by precise control of fusion

temperature and pulling speed, these parameters being controlled by the software-controlled control station. As a further safeguard, a slipping clutch (not shown) is associated with each of the stepper motors 3, the slipping clutches acting as safety override devices to prevent over tension of the fibres f1 to f4.

The four couplers C1 to C4 are pulled simultaneously, with continuous monitoring of the coupling ratios in all of the couplers at both 1300nm and 1550nm. To achieve this, four lasers L1 to L4 (two at each wavelength) and four integrating sphere detectors D1 to D4 are used (see Fig. 3). Two lasers L1 and L2, one of each wavelength, are multiplexed and launched into the fibre f1, and the other two lasers L3 and L4 are similarly launched into the fibre f4. The fibre f1 is used as a straight-through leg for the couplers C1 and C3, and the fibre f4 is used similarly to supply the couplers C2 and C4.

To calculate continuously the coupling ratio for C1 (or C2), it is necessary to energise only the lasers L1 and L2 (or L3 and L4) inputting to that coupler. The coupling ratio is established by comparison of total power out of the coupler C3 to total power out of the coupler C4.

Thus, for the coupler C1, the coupling ratio = power at (D1+D2)/power at (D1+D2+D3+D4).

For the couplers C3 and C4, the calculation is a straight forward ratio of power in each of the output legs.

Thus, for the coupler C3, the coupling ratio = power at D1/power at (D1+D2).

If the excess loss for either coupler C3 or C4 is high, there will be an error in the calculation of the coupling ratio for the couplers C1 and C2; but, since the objective is to achieve a true 25% coupling ratio port-to-port, providing the total excess loss for the device is less than 0.5dB, this can be neglected.

The outputs of the detectors D1 to D4 are fed to the control station, which controls the stepping motors 3 and the gas burners 11 to ensure a coupling ratio of 0.5 at each coupler C1 to C4. In practice, the coupling ratios are continuously calculated, and the stepping motors 3 are turned off when the desired ratios are achieved. It should be noted that the coupling ratio at the fusion temperature is not the same as that at room temperature, so the control station software must take into account of this (by setting a target coupling ratio for each of the couplers C1 to C4 that allows for this difference).

The operation of the apparatus will now be described with reference to the flow chart shown in Fig. 2. Following start up of the process (at 21), the parameters (that is to say the pulling speeds of the stepper motors 3, the acceleration and deceleration rates of the stepping motors, and the temperature range for each burner 11) are set (at 22). All output devices (that is to say the stepper motors 3 and the burners 11) are disabled (at 23), thereby preventing operation of these devices until actually required. One fibre of each pair is then loaded (at 24) into a respective cartridge 6 for pre-tapering. One fibre of each pair is pre-tapered so that the fibres of each pair have different propagation ratios. This prevents 100% overcoupling of the fibres, and ensures a similar coupling ratio over the wavelength range of from 1250 to 1600nm. The detectors D1 to D4 are then calibrated (at 25), by inputting all four lasers L1 to L4 at full power and setting the detectors to 100%. The length of pre-taper is then set (at 26), the stepping motors 3 are turned on (at 27), and the gas burners 11 are turned on (at 28). The fibres being pre-tapered are continuously checked (at 29) until the pre-set limit is reached, after which the gas burners 11 are turned off (at

30), and the motors 3 are turned off (at 31). This initial stage of the process terminates with a check (at 32) for excessive loss. This check is carried out using the lasers L1 to L4 and the detectors D1 to D4. If there is excessive loss, the fibres are removed (at 33), and the entire process is restarted.

If there is no excessive loss, the fibres are cleaved (at 34) at their detector ends to ensure consistent power output to the detectors D1 to D4. The pairs of fibres f1 and f2, f3 and f4, f1 and f3, and f2 and f4 are then loaded (at 35) into their cartridges 6. The detectors D1 to D4 are then re-calibrated (at 36), this re-calibration being necessary to take account of any losses introduced by the initial processing stage. The fibres of each pair are then twisted (at 37) through an angle typically between 360° and 720° The motors 3 and the gas burners 11 are then turned on (at 38 and 39 respectively). The coupling program is then started (at 40), that is to say the power is monitored at the detectors D1 to D4 for all the lasers L1 to L4, the coupling ratios of the couplers C1 to C4 are calculated from the measured powers at the detectors, and the measured coupling ratios are compared with the pre-set coupling ratios. The program, which is software controlled in the control station, continues until the measured coupling ratios match the pre-set coupling ratios, at which stage the coupling program ends (at 41). After allowing the fibres to cool (at 42), checks are made (at 43) to determine whether the coupling ratios match those pre-set. If not, the fibres are removed (at 33) and the entire process restarted.

If the coupling ratios are satisfactory, the insert 9 is packaged (at 44). This entails gluing a U-shaped silica channel member of 3mm diameter over each of the

couplers C1 to C4. A large area silica wafer is then glued (at 45) to the insert 9 and to the channel members. Finally, all eight fibre ends are cleaved (at 46), and the finished coupler array is removed from the apparatus (at 47). The process then finishes (at 48).

Although the apparatus described above is specifically intended for making 4 x 4 fibre couplers, it will be apparent that it could be modified to make couplers having different structures (e.g. 2 x 4, 8 x 8 etc). The apparatus could also be used to make concatenated WDM trios and Mach-Zehnder devices.

CLAIMS

1. Apparatus for manufacturing an n x n fibre coupler by forming a matrix of m 2 x 2 fibre couplers, the apparatus comprising a respective assembly for forming each of the 2 x 2 fibre couplers, and link means for linking the 2 x 2 fibre couplers in a pre-determined way, each assembly comprising a holder for holding a twisted pair of optical fibres, heating means for raising the temperature of the optical fibres to their fusion temperature, and tensioning means for stretching the optical fibres, wherein the assemblies are such that each heating means heats the associated optical fibres over a constant zone thereof during the stretching process.

2. Apparatus as claimed in claim 1, wherein n = 4 and m = 4.

3. Apparatus as claimed in claim 1 or claim 2, wherein each holder is mounted on a respective table, the tables being supported for reciprocal rectalinear movement on a common base.

4. Apparatus as claimed in claim 3, wherein each table is provided with a stepper motor for reciprocation of that table with respect to the base.

5. Apparatus as claimed in either of claims 3 and 4 when appended to claim 2, wherein the tables are mounted in pairs on opposite sides of the heating means.

6. Apparatus as claimed in claim 5, wherein the heating means is constituted by a pair of heating assemblies, the heating assemblies being positioned on opposite sides of the link means and adjacent to a respective pair of tables.

7. Apparatus as claimed in claim 6, wherein each heating assembly is constituted by a pair of gas burners, each of which is aligned with a respective twisted pair of optical fibres.

8. Apparatus as claimed in claim 7, wherein a respective ceramic crucible is associated with each of the gas burners, the ceramic crucibles being sized and shaped to surround the twisted pairs of optical fibres.

9. Apparatus as claimed in any one of claims 6 to 8, wherein the heating assemblies are supported on the base for reciprocal rectalinear movement in the same direction as the tables, and wherein each heating assembly is driven by the stepper motor of one of the adjacent tables via gearing which reduces the speed of movement of that heating assembly to half the speed of movement of the associated pair of tables.

10. Apparatus as claimed in any one of claims 1 to 9, wherein the link means comprises an insert formed with channels for directing the optical fibres in pre-determined paths between the 2 x 2 fibre couplers.

11. Apparatus as claimed in claim 10, wherein the channels are such that none of the optical fibres positioned therein are bent at a greater radius than the minimum bend radius.

12. A method of manufacturing an n x n fibre coupler. The method comprising the steps of forming a matrix of m 2 x 2 fibre couplers, and linking the 2 x 2 fibre couplers in a pre-determined way.

13. A method as claimed in claim 12, wherein each of the 2 x 2 fibre couplers is formed by heating and stretching a twisted pair of optical fibres.

14. A method as claimed in claim 13, wherein the heating of each pair of twisted optical fibres is such that the optical fibres are heated over a constant zone during the stretching of the associated pair of optical fibres.

1/4

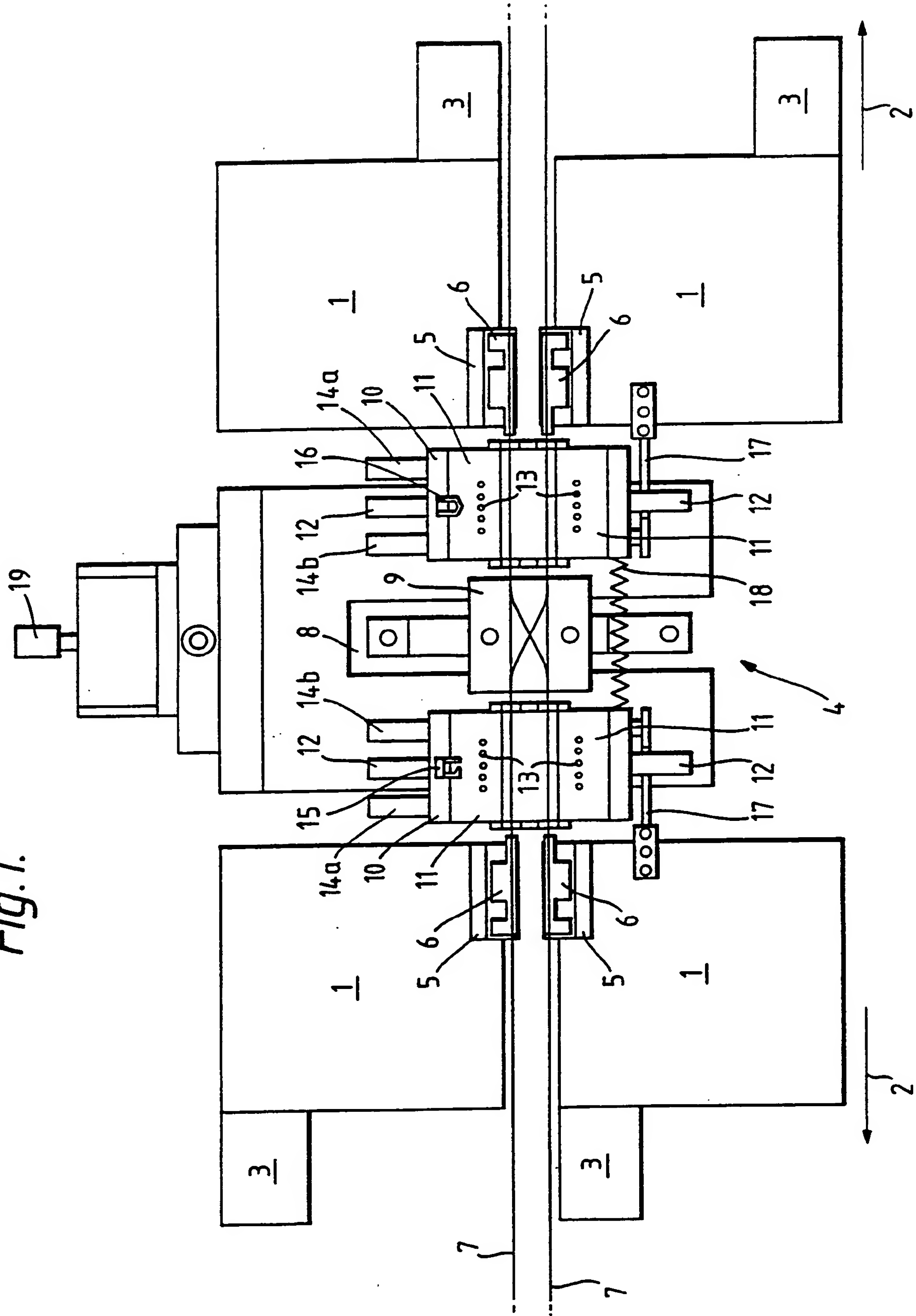

Fig.1.

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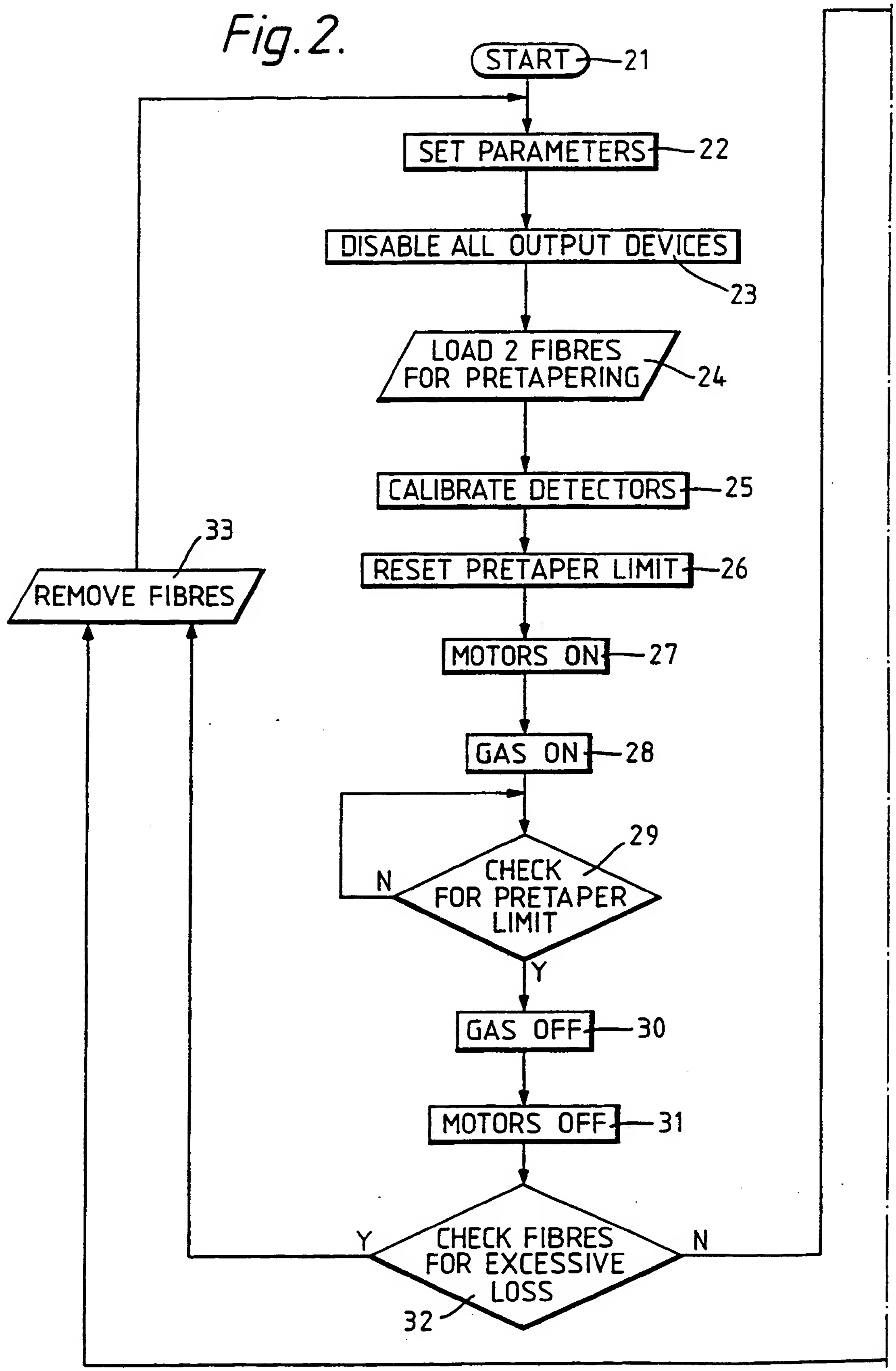
Fig. 2.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SET PARAMETERS
22
DISABLE ALL OUTPUT DEVICES
23
LOAD 2 FIBRES FOR PRETAPERING
24
CALIBRATE DETECTORS
25
RESET PRETAPER LIMIT
26
MOTORS ON
27
GAS ON
28
CHECK FOR PRETAPER LIMIT
29
N
Y
GAS OFF
30
MOTORS OFF
31
CHECK FIBRES FOR EXCESSIVE LOSS
32
Y
N
REMOVE FIBRES
33

Fig. 2(cont.)

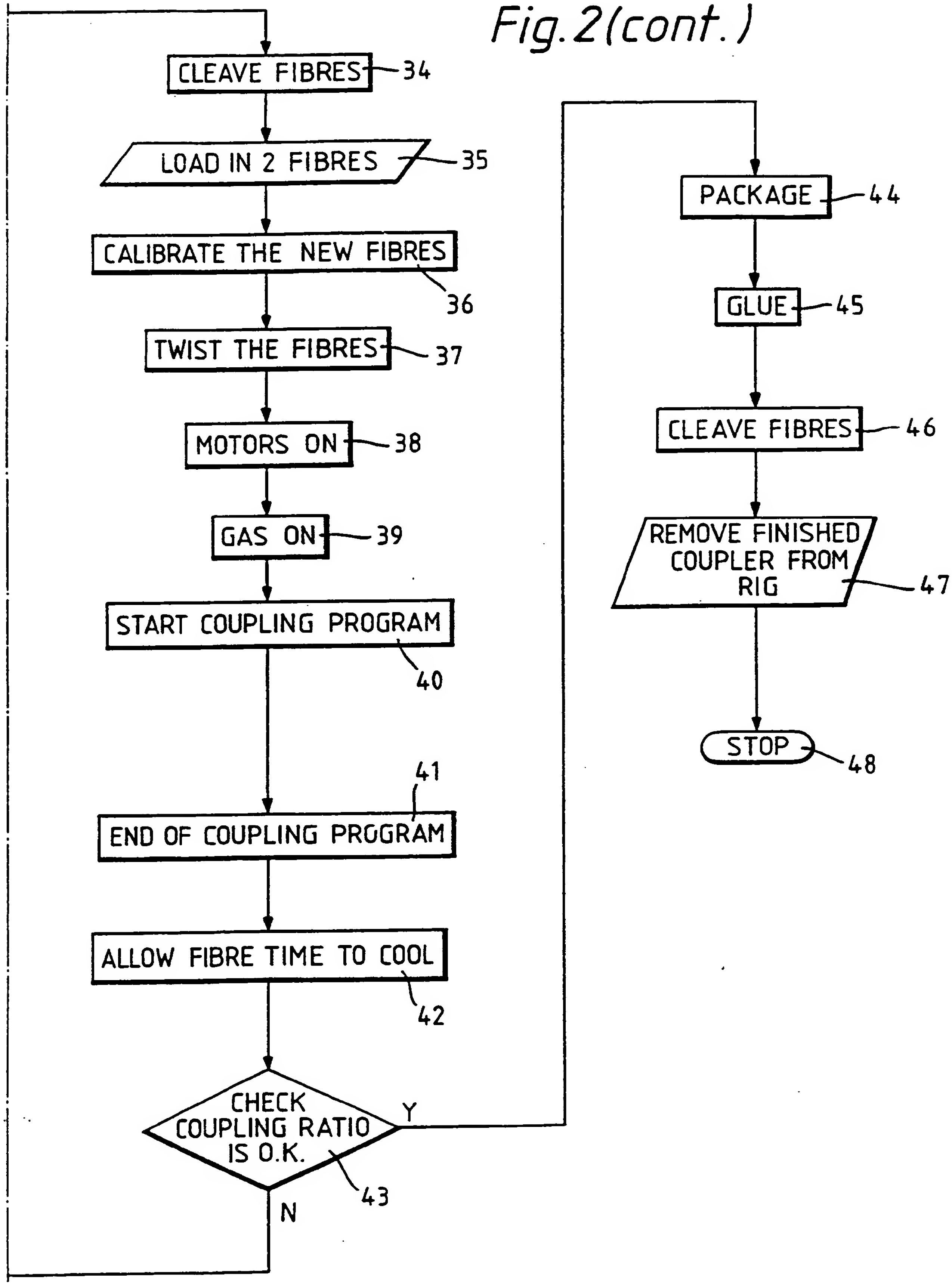

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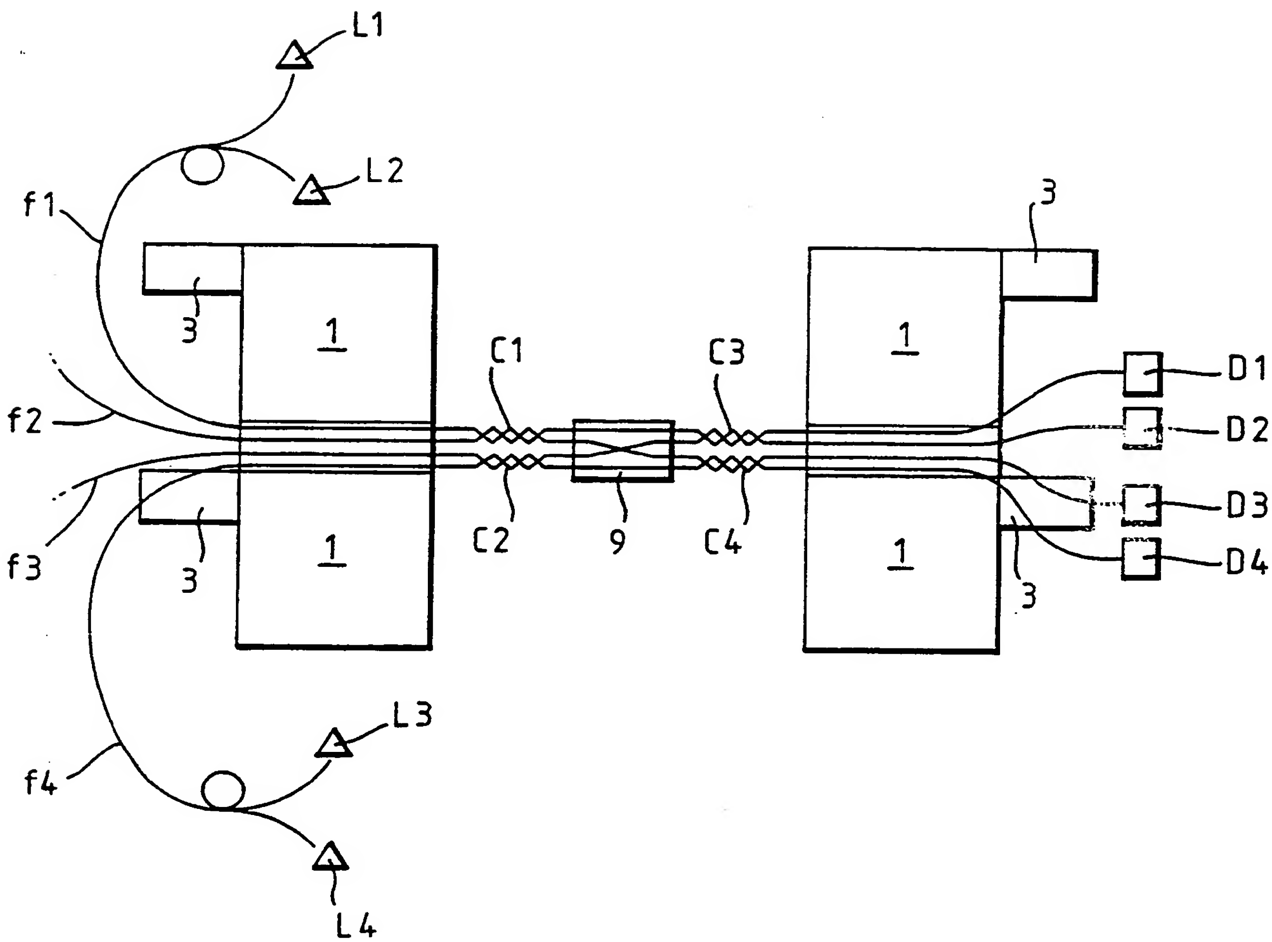
Fig. 3.



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 90/01251

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: C 03 B 37/15, G 02 B 6/28

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	C 03 B 37/, G 02 B 6/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	EP, A, 0174014 (HITACHI) 12 March 1986 see figures 7a-d,11-15; pages 20-23; page 31, lines 24-25; page 32, lines 1-25; page 33, lines 1-27; page 34, lines 1-8	12
A		1,8,13,14
	--	
X	GB, A, 2204145 (NTT) 2 November 1988 see figures 1a,1b,1g; page 7, lines 12-27; page 8, lines 1-23; page 18, lines 13-27; page 19, lines 1-11; claims	12
A		1,7,13,14
	--	
A	Patent Abstracts of Japan, volume 11, no. 62 (P-551)(2509), 25 February 1987, & JP, A, 61226711 (HITACHI) 8 October 1986 see the abstract	1,4,7,8
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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23rd November 1990	17.12.90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	N. Toribio Nuria TORIBIO

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0174014	12-03-86	JP-A- 61065204	03-04-86
		JP-A- 61113008	30-05-86
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		US-A- 4842359	27-06-89
		US-A- 4726643	23-02-88
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		JP-A- 63205616	25-08-88
		JP-A- 1120510	12-05-89
		US-A- 4869570	26-09-89

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